ATMOSPHERIC SPECTROSCOPY

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Wave Propagation Laboratory

NOAA

Boulder, Colorado

Final Report

30 November 1970

Sponsored by

ARPA Order No. 1390 Program Code 9E50

3/19/69 to 9/30/70

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Atmospheric Spectroscopy

Summary Report

This report covers the work performed under ARPA Order No. 1390 Program Code 9E50 for the period March 19, 1969 to September 30, 1970.

The purpose of this project was to provide data on the absorption properties of atmospheric gases (water vapor, carbon dioxide, nitrous oxide, ozone, methane and carbon monoxide) and their effects upon the transmission of electromagnetic radiation. This required that line parameters (spectral position, intensity, halfwidth and energy levels) be computed, based upon theoretical calculations and verified where possible by experimental data. The important spectral regions from $1/cm^{-1}$ (10000 μm) to $10,000/cm^{-1}$ (1 μm) have been covered for these molecules. These data have been put in a uniform format suitable for use in computers.

From these data it is possible to compute the absorption of radiation over any path with any concentration of absorber. This makes it possible to predict the effectiveness of sensing, tracking and guidance devices. These data are also necessary for calculating the heat balance and radiative transfer of planetary atmospheres. A more detailed account of the work appears in the body of the report.

There are still gaps in the data which must be filled and data for some regions need to be improved in order to be able to achieve the best results in making calculations over the entire spectral range.

Atmospheric Spectroscopy

Final Report

30 November 1970

Introduction

Under the general mission of the ESSA (now NOAA) Research Laboratories to study environmental processes, the Wave Propagation Laboratory has been engaged in studies of the absorption properties of atmospheric gases under the sponsorship of ARPA. This activity began in 1961 under the direction of Dr. D. M. Gates and has continued since 1964 under the direction of R. F. Calfee who has directed the work for the present contract.

This report covers the work performed under ARPA Order No. 1390 Program Code No. 9E50 for the period 19 March 1969 to 30 September 1970. This was a continuation of the work carried out under ARPA Order No. 250-61 Code No. 7400-DO.

Personnel engaged on the present contract were R. F. Calfee, V. E. Derr, R. G. Strauch, F. McGraw, T. Doyle and T. Burrows.

Work Accomplished under ARPA Order 390

Over the period of years since the beginning of the work to calculate and assemble data on molecular line parameters for atmospheric gases (H_2O, CO_2, N_2O, O_3, CH_4 and CO), the data has accumulated in a variety of forms. At the November 1968 meeting of the Group on Atmospheric Transmission Studies it was agreed that a standard format should be set up for recording the data. At this meeting it was also agreed that a standardized set of units should be used for the line

parameters of all gases. The quantity to be used for line positions is the wavenumber with units of reciprocal centimeters (cm^{-1}). The intensity of lines is to be expressed in cm^{-1}/ (molecule / cm^2) arbitrary cut off values for line intensities of the various gases were also established for the purpose of limiting the compiled data to that essential to making calculations of absorption properties of the earth's atmosphere.

These decisions meant that all existing data on file from a number of sources in a variety of formats had to be made compatible and converted to the established standards. The conversion to the uniform format was completed and all data is available on standard 80 column IBM cards or on magnetic tape. A sample page showing the data available is included at the end of this report.

From information furnished by Dr. W. S. Benedict on the molecular constants for carbon dioxide, the necessary parameters were obtained for generating the line parameter data for the thousands of lines of significance to the earth's atmosphere in the 4.3, 10.6 and 15 μm regions. These line parameter data were generated and added to the compilation of data.

The necessary energy level data for the water vapor bands in the 0.82 μm region of the spectrum were programmed to provide spectral line data for this region. These data have been added to the compilation.

As a part of the ESSA mission on environmental studies, a chart was prepared showing the extent of absorption by atmospheric gases throughout the infrared and microwave regions of the spectrum. This chart includes the pollutant gases as well as the naturally accuring absorbing gases. The extent of available knowledge for each gas in the

various parts of the spectrum is indicated by a difference in the line drawn to show where absorption by the individual gases takes place. A copy of this chart is included at the end of this report.

A table has been prepared showing the locations and band intensities of the normally occurring gases for which line parameter data is available. The information in this table has also been put into graphic form using vertical lines centered at the appropriate positions to show the relative intensities of the absorbing bands. The use of this table and graphs gives a good picture of the significance of each of the gases as a potential source of difficulty in the transmission of radiation through the atmosphere. The table and corresponding graphs are included as a part of this report.

The purpose in calculating and accumulating all the data on these gases has been to make it possible to compute the transmission characteristics of the atmosphere over any spectral region. Based on the line parameter data, computer programs have been developed which will provide a spectrum of the absorption by any combination of gases over any path at any desired resolution as a function of temperature, pressure and concentration of gases. These programs have been designed to include the self broadening effects of the gases in window regions where this effect is predominant. The effects of nitrogen-nitrogen collision-induced absorption have been incorporated into the programs to take into account this phenomenon where it is a significant feature of the absorption process.

Recommendations

Now that better experimental work has become available, improvements and additions should be made to the water vapor bands in the 1 to 4 μm region. The line parameters for the oxygen 17 and 18

and carbon 13 isotopic species of carbon dioxide need to be determined and added to the accumulated data. Further comparisons between calculated and laboratory spectra of ozone need to be made to be sure that the best line parameter values have been determined.

Although a major part of the work has been done in determining the line parameters of atmospheric gases the parts that remain to be done will require considerable effort since these regions are in areas where there is a great deal of overlapping and interference.

While the emphasis in this program has been placed upon an understanding of the naturally occurring atmospheric absorbers, the significance of pollutants should not be overlooked. Until the same kind of line parameter data is available for pollutant gases it will not be possible to carry out a careful analysis of their effect upon transmission through the atmosphere.

SAMPLE LIST
PARAMETERS OF ATMOSPHERIC GASES
PREPARED BY RF CALFEE
WAVE PROPAGATION LAB
ESSA BOULDER COLO

WAVE NUMBER 1/CM	LINE INTENSITY (1/CM) (MOL/SQ CM)	* HALF WIDTH 1/CM	LOWER STATE ENERGY 1/CM	QUANTUN MECHANICAL TRANSITION IDENTIFICATIONS	CODING NUMBERS
1131.169	8.805-023		178.741	17 5 13 17 4 14 1 0 0 0 0 0	68 666 3
1131.190	3.028-026	.054	2009.870	9 5 4 9 8 1 0 1 0 0 0 0	67 161 1
1131.197	8.835-023		164.440	16 5 11 16 4 12 1 0 0 0 0 0	68 666 3
1131.229	8.775-023		150.974	15 5 11 15 4 12 1 0 0 0 0 0	68 666 3
1131.252	8.627-023		138.357	14 5 9 14 4 10 1 0 0 0 0 0	68 666 3
1131.255	4.965-022		905.068	0 2 0 0 0 0 0 P 46	89 446 4
1131.275	8.374-023		126.581	13 5 9 13 4 10 1 0 0 0 0 0	68 666 3
1131.293	8.017-023		115.649	12 5 7 12 4 8 1 0 0 0 0 0	68 666 3
1131.309	7.544-023		105.558	11 5 7 11 4 8 1 0 0 0 0 0	68 666 3
1131.323	6.956-023		96.310	10 5 5 10 4 6 1 0 0 0 0 0	68 666 3
1131.335	6.238-023		87.904	9 5 5 9 4 6 1 0 0 0 0 0	68 666 3
1131.344	5.379-023		80.339	8 5 3 8 4 4 1 0 0 0 0 0	68 666 3
1131.352	4.367-023		73.615	7 5 3 7 4 4 1 0 0 0 0 0	68 666 3
1131.359	3.176-023		67.733	6 5 1 6 4 2 1 0 0 0 0 0	68 666 3
1131.364	1.754-023		62.691	5 5 1 5 4 2 1 0 0 0 0 0	68 666 3
1131.367	9.222-022		450.073	33 2 32 32 1 31 1 0 0 0 0 0	68 666 3
1131.441	3.742-024		842.865	36 10 26 37 9 29 1 0 0 0 0 0	68 666 3
1131.502	1.054-023		661.736	40 1 39 40 0 40 1 0 0 0 0 0	68 666 3
1131.502	5.148-024		365.653	21 8 14 22 7 15 1 0 0 0 0 0	68 666 3
1131.610	1.259-026	.045	2748.140	13 3 11 13 6 8 0 1 0 0 0 0	67 161 1
1131.655	2.989-022		682.692	40 2 38 39 3 37 1 0 0 0 0 0	68 666 3
1131.775	4.836-022		128.116	17 3 15 16 2 14 1 0 0 0 0 0	68 666 3
1131.801	2.488-022		51.719	8 4 4 7 3 5 1 0 0 0 0 0	68 666 3
1131.821	7.566-022		535.038	36 1 35 35 2 34 1 0 0 0 0 0	68 666 3
1131.874	6.648-024		565.168	28 9 19 29 8 22 1 0 0 0 0 0	68 666 3
1131.955	3.861-024		979.938	48 2 46 48 1 47 1 0 0 0 0 0	68 666 3
1132.031	5.860-022		866.589	0 2 0 0 0 0 0 P 45	89 446 4
1132.043	1.280-021		482.140	35 1 35 34 0 34 1 0 0 0 0 0	68 666 3
1132.060	3.096-027	.085	573.810	5 2 4 6 4 3 0 1 0 0 0 0	67 162 1
1132.060	7.253-026	.069	1024.300	9 2 8 10 3 7 0 1 0 0 0 0	67 162 1
1132.350	3.917-024		811.812	35 10 26 36 9 27 1 0 0 0 0 0	68 666 3
1132.358	4.282-024		347.167	20 8 12 21 7 15 1 0 0 0 0 0	68 666 3
1132.616	4.297-022		113.084	16 3 13 15 2 14 1 0 0 0 0 0	68 666 3
1132.628	2.759-022		58.447	9 4 6 8 3 5 1 0 0 0 0 0	68 666 3
1132.668	8.158-022		505.450	35 2 34 34 1 33 1 0 0 0 0 0	68 666 3
1132.702	5.900-024		694.417	41 2 40 41 1 41 1 0 0 0 0 0	68 666 3
1132.743	6.387-024		540.811	27 9 19 28 8 20 1 0 0 0 0 0	68 666 3
1132.762	1.045-023		1374.875	56 4 52 55 5 51 1 0 0 0 0 0	68 666 3
1132.806	1.174-021		510.145	36 0 36 35 1 35 1 0 0 0 0 0	68 666 3
1132.807	6.885-022		828.943	0 2 0 0 0 0 0 P 44	89 446 4
1132.826	5.111-022		158.160	19 3 17 18 2 16 1 0 0 0 0 0	68 666 3
1132.840	4.393-026	.065	1200.130	8 1 8 9 2 7 0 1 0 0 0 0	67 171 1
1133.070	7.834-027	.057	2254.340	10 5 5 10 8 2 0 1 0 0 0 0	67 161 1
1133.090	7.122-026	.080	576.820	6 0 6 7 3 5 0 1 0 0 0 0	67 162 1
1133.217	7.399-024		727.862	42 1 41 42 0 42 1 0 0 0 0 0	68 666 3

* Only water vapor halfwidths are known well enough to list individual values.

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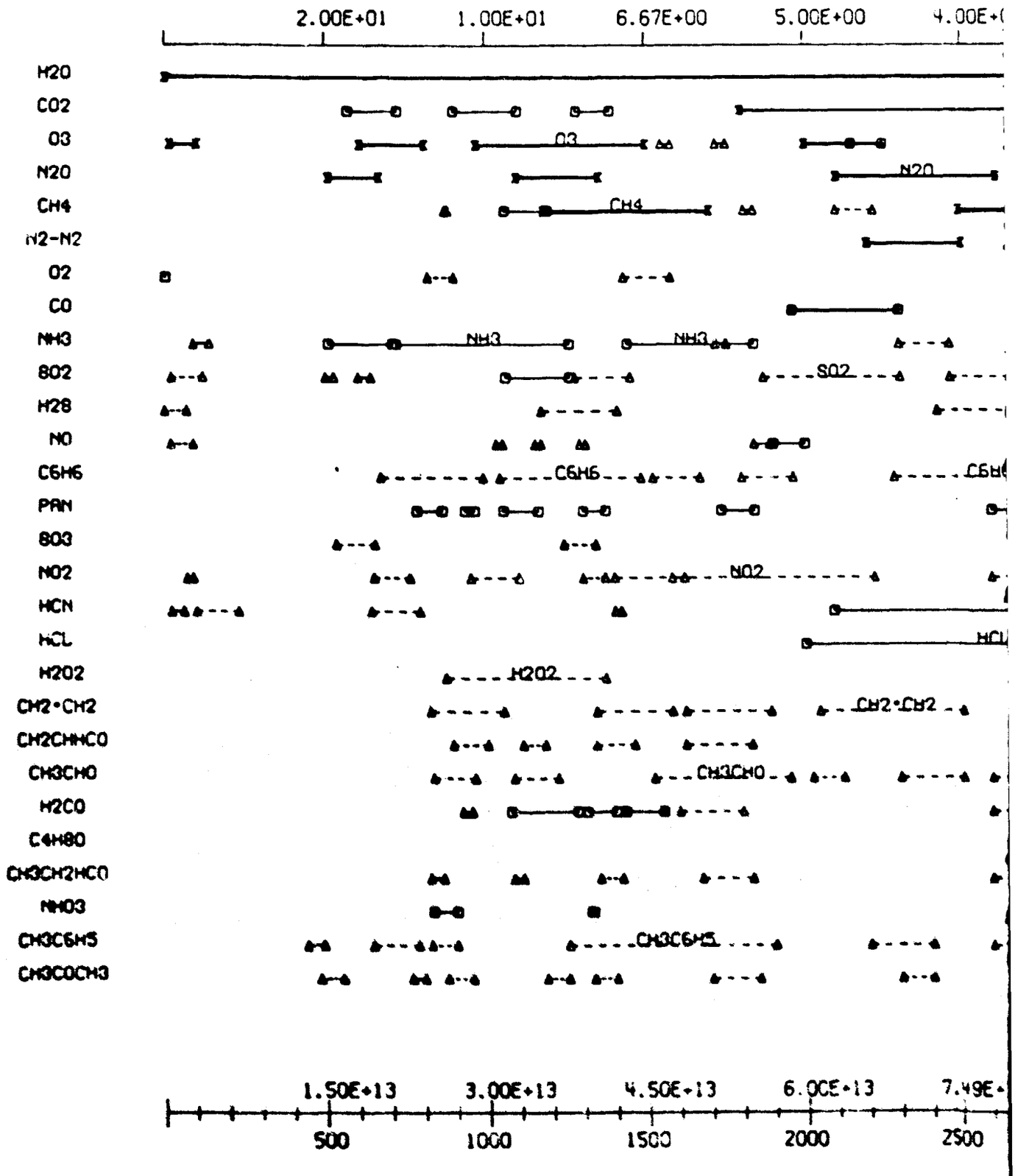
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N2O
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CO
NH3
SO2
H2S
NO
C6H6
PAN
SO3
NO2
HCN
HCL
H2O2
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H2CO
C4H8O
CH3CH2HCO
NH03
CH3C6H5
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1000
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2500

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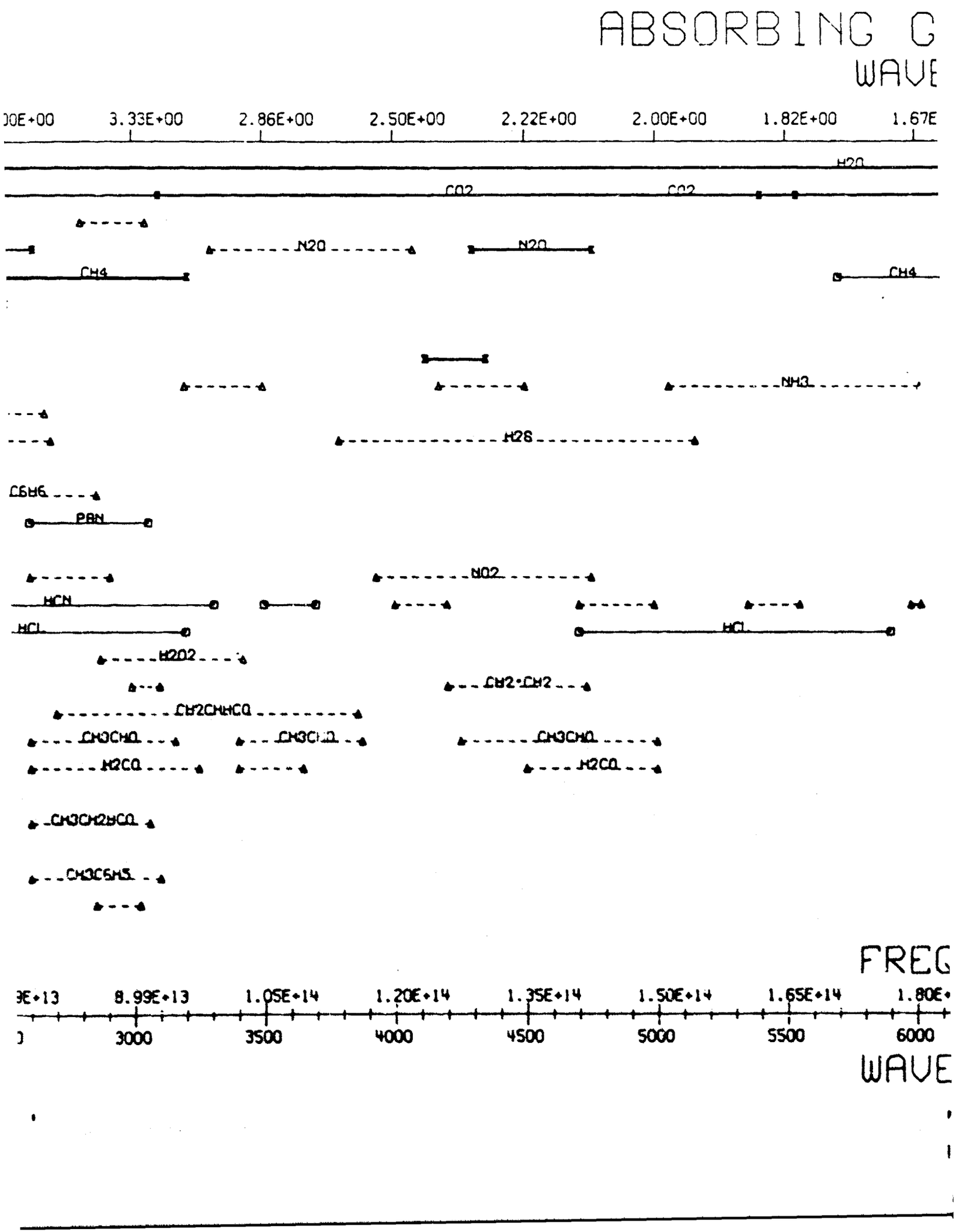
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WAVE
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1.67E
H2O
CO2
CO2
N2O
N2O
CH4
CH4
NH3
H2S
C6H6
PAN
NO2
HCN
HCl
HCl
H2O2
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CH3CHO
H2CO
H2CO
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FREQ
3E+13
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1.0SE+14
1.20E+14
1.3SE+14
1.50E+14
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)
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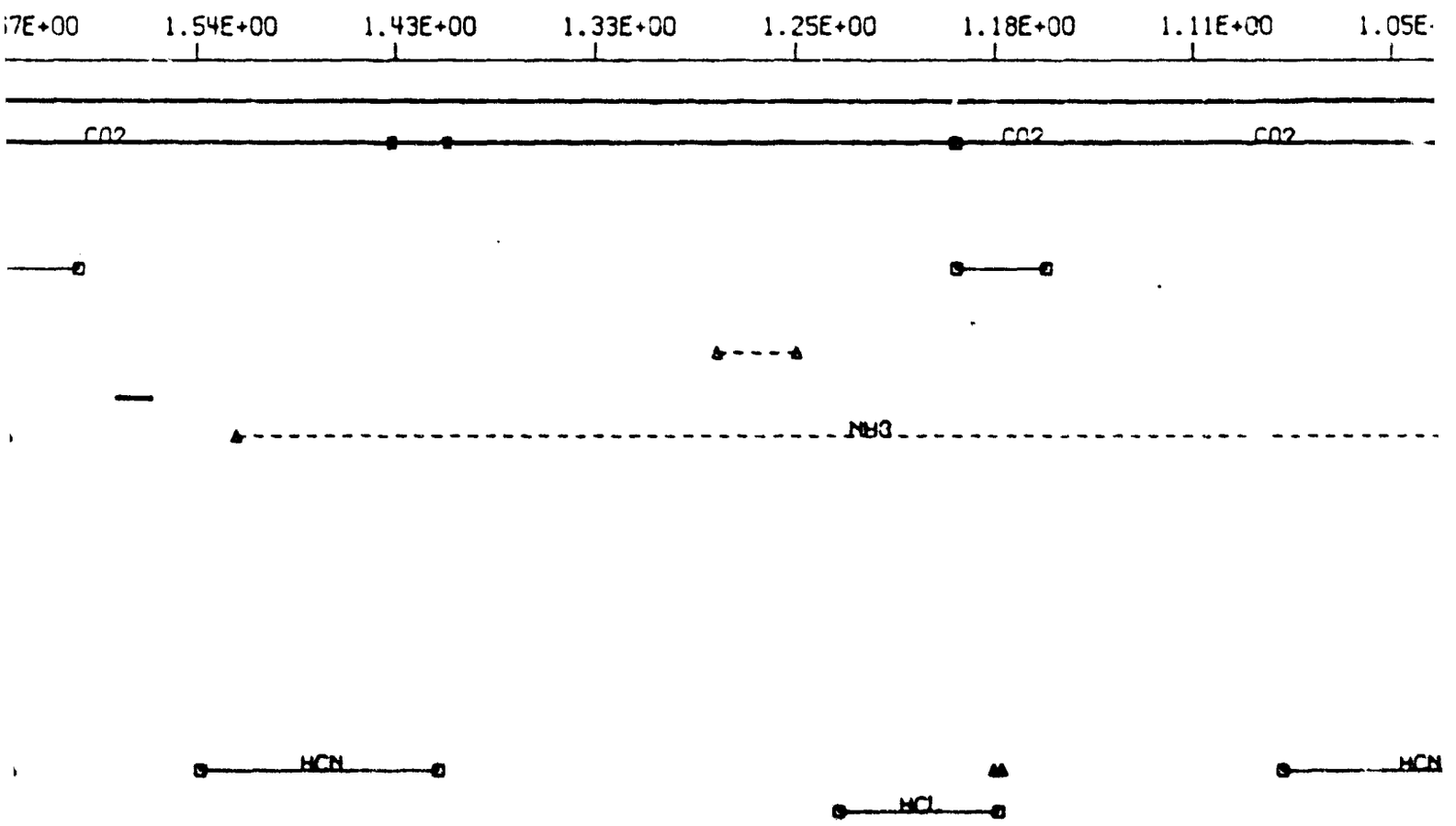
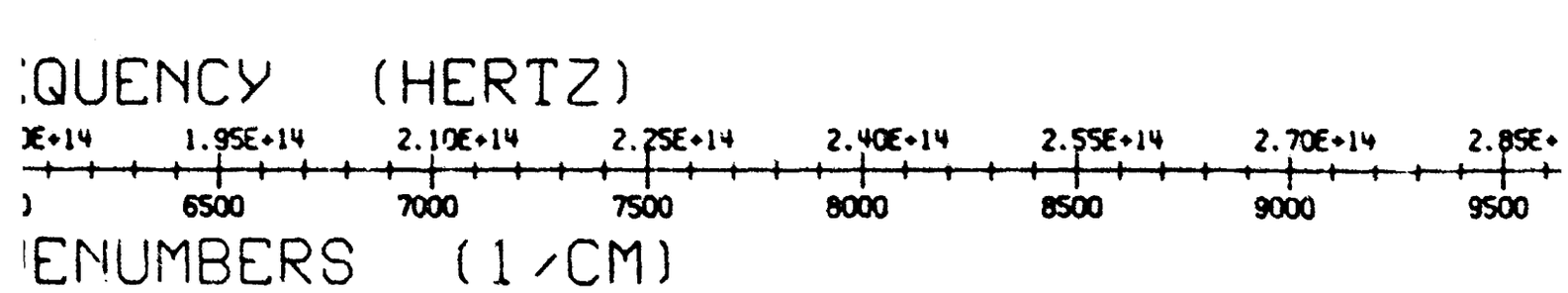
WAVE

C

GASES FOUND IN THE ATMOSPHERE





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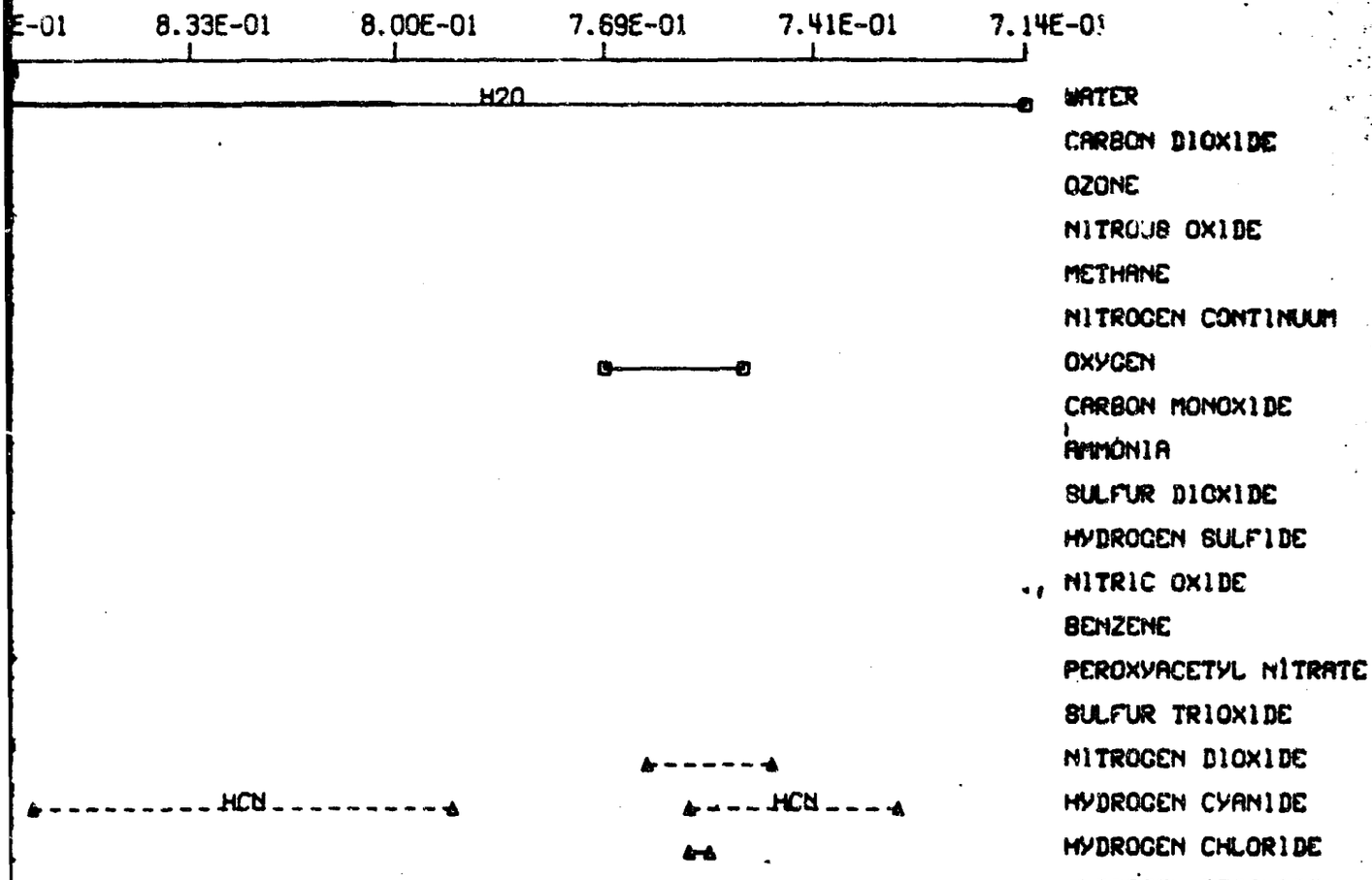


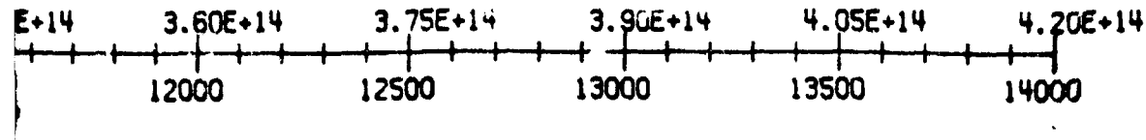
WATER
CARBON DIOXIDE
OZONE
NITROUS OXIDE
METHANE
NITROGEN CONTINUUM
OXYGEN
CARBON MONOXIDE
AMMONIA
SULFUR DIOXIDE
HYDROGEN SULFIDE
NITRIC OXIDE
BENZENE
PEROXYACETYL NITRATE
SULFUR TRIOXIDE
NITROGEN DIOXIDE
HYDROGEN CYANIDE
HYDROGEN CHLORIDE
HYDROGEN PEROXIDE
ETHYLENE
ACROLEIN
ACETALDEHYDE
FORMALDEHYDE
BUTYRALDEHYDE
PROPIONALDEHYDE
NITRIC ACID
TOLUENE
ACETONE

A chart showing the present status of the knowledge concerning atmospheric absorbing gases.

HEAVY SOLID LINE Indicates that line positions and intensities are known.

LIGHT SOLID LINE Indicates that only line positions are known.

DASHED LINE Indicates that only band information is available.



ATMOSPHERIC ABSORBING BANDS
PREPARED BY RF CALFEE
WAVE PROPAGATION LAB
ESSA BOULDER COLO
MAY 1970

BAND CENTER WAVE NUMBER (1/CM)	BAND CENTER WAVE LENGTH (MU)	BAND INTENSITY (1/CM) (MOL/SQ CM)	VIBRATIONAL TRANSITION UPPER STATE	VIBRATIONAL TRANSITION LOWER STATE	GAS	ISO
321.971	31.059	1.239-026	20002	00011	OCO	626
448.012	22.318	8.556-027	20001	00011	OCO	626
471.512	21.208	9.746-025	20003	11101	OCO	626
479.908	20.837	1.223-025	13302	12201	OCO	626
508.141	19.680	5.163-021	12202	11101	OCO	626
510.337	19.595	4.025-025	21103	20002	OCO	626
542.186	18.444	7.105-025	21102	20001	OCO	626
544.283	18.373	2.723-022	11102	10001	OCO	626
568.664	17.585	7.157-024	13302	04401	OCO	626
578.605	17.283	3.765-024	21102	12201	OCO	626
579.367	17.260	6.994-020	0200	0110	NNO	446
581.697	17.191	1.934-022	12202	03301	OCO	626
588.767	16.985	1.228-018	0110	0000	NNO	446
588.983	16.978	6.994-020	0220	0110	NNO	446
594.248	16.828	9.077-023	20002	11101	OCO	626
596.457	16.766	2.574-023	21103	12202	OCO	626
597.341	16.741	5.208-021	11102	02201	OCO	626
605.910	16.504	9.077-027	20013	11112	OCO	626
608.828	16.425	1.748-024	10012	01111	OCO	626
615.907	16.236	6.889-022	20003	11102	OCO	626
618.033	16.180	1.436-019	10002	01101	OCO	626
633.073	15.796	6.488-023	21103	20003	OCO	626
640.266	15.619	2.113-026	12212	11112	OCO	626
647.058	15.455	2.22-020	11102	10002	OCO	626
652.536	15.325	1.652-021	12202	11102	OCO	626
654.874	15.270	8.854-023	01111	00011	OCO	626
655.261	15.261	7.410-025	02211	01111	OCO	626
655.637	15.252	9.895-023	13302	12202	OCO	626
656.214	15.239	2.574-026	04411	03311	OCO	626
667.379	14.984	8.258-018	01101	00001	OCO	626
667.750	14.976	6.488-019	02201	01101	OCO	626
668.180	14.966	3.824-020	03301	02201	OCO	626
668.227	14.965	3.117-023	21102	20002	OCO	626
668.671	14.955	1.845-021	04401	03301	OCO	626
669.219	14.943	9.761-023	05501	04401	OCO	626
681.600	14.671	4.598-023	13301	12201	OCO	626
683.873	14.623	9.047-021	12201	11101	OCO	626
688.678	14.520	1.488-020	11101	10001	OCO	626
701.000	14.265	7.435-019	010	000	03	666
703.501	14.215	2.463-023	21101	20001	OCO	626
710.765	14.069	2.024-024	10011	01111	OCO	626
720.289	13.883	4.784-022	20001	11101	OCO	626
720.808	13.873	1.853-019	10001	01101	OCO	626
738.643	13.538	3.021-022	20002	11102	OCO	626

739.920	13.515	1.756-023	21101	12201	OCO	626
741.735	13.482	7.901-021	11101	02201	OCO	626
754.334	13.257	1.607-023	21102	12202	OCO	626
757.426	13.203	3.288-022	12201	03301	OCO	626
770.355	12.981	1.351-023	13301	04401	OCO	626
790.963	12.643	5.483-024	21102	20003	OCO	626
791.452	12.635	1.123-021	11101	10002	OCO	626
815.690	12.260	2.202-026	10012	20001	OCO	626
828.265	12.073	2.009-023	12201	11102	OCO	626
829.541	12.055	1.153-024	21101	20002	OCO	626
857.329	11.664	1.097-024	13301	12202	OCO	626
864.684	11.565	4.315-024	20001	11102	OCO	626
898.542	11.129	2.634-024	02211	12201	OCO	626
915.644	10.921	1.949-025	21101	12202	OCO	626
917.027	10.898	8.705-025	10011	20001	OCO	626
927.151	10.786	7.113-023	01111	11101	OCO	626
941.731	10.619	1.146-024	10012	20002	OCO	626
952.278	10.501	6.398-026	21101	20003	OCO	626
960.955	10.406	4.910-022	00011	10001	OCO	626
1008.000	9.921	9.534-021	101	100	O3	666
1008.000	9.921	2.506-020	001	000	O3	686
1021.000	9.794	4.248-019	011	010	O3	666
1027.000	9.737	1.627-019	002	001	O3	666
1029.000	9.718	6.695-020	001	00C	O3	668
1042.096	9.596	1.292-017	001	000	O3	666
1043.668	9.582	1.176-024	10011	20002	OCO	626
1060.921	9.426	7.775-027	20013	30004	OCO	626
1063.730	9.401	6.324-022	00011	10002	OCO	626
1064.467	9.394	2.329-024	10012	20003	OCO	626
1065.995	9.381	2.120-026	12212	22203	OCO	626
1068.017	9.363	2.664-026	01121	11112	OCO	626
1071.546	9.332	1.080-022	01111	11102	OCO	626
1074.271	9.309	4.538-024	02211	12202	OCO	626
1103.157	9.065	3.330-019	100	000	O3	666
1166.403	8.573	8.184-027	10011	20003	OCO	626
1168.134	8.561	4.464-019	0200	0000	NNO	446
1284.907	7.783	8.705-018	1000	0000	NNO	446
1291.501	7.743	3.125-019	1110	0110	NNO	446
1306.000	7.657	7.048-018	0001	0000	CH4	21
1403.480	7.125	3.210-021	010	000	HOH	162
1533.000	6.523	7.516-020	0100	0000	CH4	21
1556.870	6.423	2.340-017	020	010	HOH	161
1587.380	6.300	2.330-020	010	000	HOH	181
1590.550	6.287	4.320-021	010	000	HOH	171
1594.730	6.271	1.170-017	010	000	HOH	161
1846.321	5.416	3.274-026	21103	02201	OCO	626
1856.820	5.386	2.604-026	20003	01101	OCO	636
1860.210	5.376	4.464-027	30004	11102	OCO	626
1865.615	5.360	6.696-027	30003	11101	OCO	626
1880.901	5.317	1.562-024	20003	01101	OCO	626
1883.180	5.310	1.488-025	12202	01101	OCO	636
1889.430	5.293	1.265-025	22203	11102	OCO	626
1894.840	5.277	3.720-026	14402	03301	OCO	626
1896.038	5.274	1.101-024	21103	10002	OCO	626

1896.490	5.273	1.488-024	11102	00001	OCO	636
1901.600	5.259	2.976-024	11102	00001	OCO	628
1905.129	5.249	1.786-024	13302	02201	OCO	626
1917.663	5.215	4.226-023	12202	01101	OCO	626
1930.985	5.179	8.184-026	22202	11101	OCO	626
1932.470	5.175	4.092-022	11102	00001	OCO	626
1951.153	5.125	7.068-025	21102	10001	OCO	626
1996.100	5.010	1.488-025	20002	01101	OCO	636
2003.841	4.990	8.184-025	20002	01101	OCO	626
2004.211	4.989	1.176-025	21102	02201	OCO	626
2010.010	4.975	1.339-026	30003	11102	OCO	626
2037.093	4.909	1.860-023	11101	00001	OCO	636
2049.700	4.879	3.720-024	11101	00001	OCO	628
2062.000	4.850	5.208-025	11101	00001	OCO	627
2062.350	4.849	2.400-019	100	010	HOH	161
2075.380	4.818	8.482-025	22202	11102	OCO	626
2076.865	4.815	2.232-021	11101	00001	OCO	626
2093.356	4.777	3.958-022	12201	01101	OCO	626
2096.000	4.771	9.706-018	1	0	CO	26
2102.000	4.757	1.488-024	20001	01101	OCO	636
2106.000	4.748	1.335-018	101	000	03	666
2107.021	4.746	2.530-023	13301	02201	OCO	626
2112.403	4.734	1.116-023	21101	10001	OCO	626
2117.235	4.723	1.176-025	12212	12201	OCO	626
2119.540	4.718	1.562-024	14401	03301	OCO	626
2120.335	4.716	1.190-024	22201	11101	OCO	626
2127.231	4.701	2.470-025	12212	12201	OCO	626
2129.775	4.695	1.302-023	20001	01101	OCO	626
2132.065	4.690	1.503-026	21112	21101	OCO	626
2135.735	4.682	3.318-026	21113	21102	OCO	626
2148.035	4.655	5.952-025	30001	11101	OCO	626
2161.190	4.627	3.900-019	001	010	HOH	161
2165.461	4.618	5.952-024	21101	02201	OCO	626
2170.841	4.607	5.074-024	11112	11101	OCO	626
2170.849	4.606	9.806-024	11112	11101	OCO	626
2180.676	4.586	9.188-026	20012	20001	OCO	626
2182.400	4.582	1.722-025	20013	20002	OCO	626
2223.756	4.497	6.882-017	0001	0000	NNO	446
2224.657	4.495	1.272-022	10012	10001	OCO	626
2286.779	4.373	3.884-023	05511	05501	OCO	626
2288.352	4.370	2.366-023	13311	13301	OCO	626
2289.890	4.367	1.786-023	21111	21101	OCO	626
2290.715	4.365	3.125-023	13312	13302	OCO	626
2293.416	4.360	3.839-023	21112	21102	OCO	626
2293.615	4.360	7.931-023	21113	21103	OCO	626
2299.219	4.349	9.791-022	04411	04401	OCO	626
2301.017	4.346	6.339-022	12211	12201	OCO	626
2301.918	4.344	2.887-024	10021	10011	OCO	626
2302.384	4.343	4.724-024	10022	10012	OCO	626
2302.508	4.343	1.324-022	20011	20001	OCO	626
2302.973	4.342	7.366-022	12212	12202	OCO	626
2303.246	4.338	4.352-022	20013	20003	OCO	626
2306.720	4.335	2.396-022	20012	20002	OCO	626
2311.675	4.326	2.455-020	03311	03301	OCO	626

2311.715	4.326	3.586-022	01121	01111	OCO	626
2313.764	4.322	1.711-020	11111	11101	OCO	626
2315.246	4.319	3.422-020	11112	11102	OCO	626
2324.148	4.303	6.160-019	02211	02201	OCO	626
2324.182	4.303	2.098-021	00021	00011	OCO	626
2326.594	4.298	1.183-019	10011	10001	OCO	626
2327.432	4.297	1.934-019	10012	10002	OCO	626
2336.637	4.280	1.533-017	01111	01101	OCO	626
2349.142	4.257	9.598-017	00011	00001	OCO	626
2428.549	4.118	1.458-025	20011	20002	OCO	626
2429.369	4.116	1.059-022	10011	10002	OCO	626
2429.456	4.116	2.563-025	20012	20003	OCO	626
2458.158	4.068	8.035-024	11111	11102	OCO	626
2461.998	4.062	4.278-019	1200	0000	NNO	446
2490.004	4.016	3.028-027	13311	13302	OCO	626
2563.341	3.901	1.637-018	2000	0000	NNO	446
2723.700	3.671	5.400-022	100	000	HOH	162
2782.040	3.594	6.300-023	020	000	HOH	162
3018.000	3.313	1.199-017	0010	0000	CH4	21
3125.300	3.200	7.403-027	30004	01101	OCO	626
3139.100	3.186	1.320-022	020	000	HOH	181
3145.350	3.179	4.920-023	020	000	HOH	161
3151.600	3.173	6.630-020	020	000	HOH	161
3154.500	3.170	7.410-026	22206	01101	OCO	626
3181.450	3.143	2.128-025	05101	00001	OCO	626
3181.463	3.143	6.867-025	21103	00001	OCO	626
3275.100	3.053	1.019-024	30003	01101	OCO	626
3339.343	2.995	4.166-024	21102	00001	OCO	626
3342.928	2.991	1.475-026	22213	12201	OCO	626
3393.000	2.947	9.226-026		00001	OCO	636
3398.100	2.943	1.853-025	30002	01101	OCO	626
3398.213	2.943	8.258-025	21113	11101	OCO	626
3404.875	2.937	3.709-026	30014	20002	OCO	626
3430.770	2.915	3.155-026	30013	20001	OCO	626
3465.436	2.886	1.786-023	20013	10001	OCO	626
3473.680	2.879	3.422-023	12212	02201	OCO	636
3490.350	2.865	4.628-023	10012	00001	OCO	638
3498.720	2.858	7.314-022	11112	01101	OCO	636
3500.694	2.857	6.026-024	21101	00001	OCO	626
3504.944	2.853	9.508-024	14412	04401	OCO	626
3527.610	2.835	1.034-023	30014	20003	OCO	626
3527.747	2.835	7.470-024	22212	12201	OCO	626
3528.049	2.834	1.220-022	13312	03301	OCO	626
3528.250	2.834	1.295-022	13312	03301	OCO	626
3533.975	2.830	3.527-024	11122	01111	OCO	626
3538.950	2.826	4.449-022		01101	OCO	628
3542.570	2.823	3.147-022	40002	11102	OCO	626
3542.608	2.823	6.339-022	21113	11102	OCO	626
3550.708	2.816	1.953-024	30012	20001	OCO	626
3552.820	2.815	3.452-021	12212	02201	OCO	626
3552.850	2.815	6.250-021	12212	02201	OCO	626
3555.860	2.812	8.333-023	21112	11101	OCO	626
3555.894	2.812	2.202-022	21112	11101	OCO	626
3556.749	2.812	6.287-024	30013	20002	OCO	626

3566.087	2.804	2.083-023	10022	00011	OCO	626
3568.221	2.803	3.378-021	20012	10002	OCO	626
3571.110	2.800	6.495-021	10011	00001	OCO	628
3578.670	2.794	2.753-023	22213	12202	OCO	626
3580.290	2.793	9.479-020	11112	01101	OCO	626
3580.334	2.793	1.607-019	11112	01101	OCO	626
3587.510	2.787	7.031-023	10011	00001	OCO	638
3589.646	2.786	1.786-021	20012	10001	OCO	626
3591.360	2.784	1.094-021		00001	OCO	627
3639.180	2.748	1.518-021	11111	01101	OCO	636
3641.530	2.746	6.294-023	31101	02201	OCO	636
3649.680	2.740	1.920-021	100	000	HOH	181
3653.390	2.737	3.000-022	100	000	HOH	171
3657.080	2.734	8.100-019	100	000	HOH	161
3667.557	2.727	3.832-023	10021	00011	OCO	626
3675.110	2.721	4.777-021	10012	00001	OCO	628
3675.694	2.721	6.622-024	11121	01111	OCO	626
3676.749	2.720	9.151-024	30012	20002	OCO	626
3679.547	2.718	9.858-024	30013	20003	OCO	626
3684.050	2.714	3.884-022		01101	OCO	628
3692.421	2.708	4.241-021	20012	10002	OCO	626
3693.430	2.708	1.131-021		00001	OCO	627
3700.270	2.703	2.411-022	21112	11102	OCO	626
3700.289	2.702	7.098-022	21112	11102	OCO	626
3703.489	2.700	3.006-023	22212	12202	OCO	626
3705.939	2.698	5.506-024	30011	20001	OCO	626
3711.475	2.694	3.501-021	20011	10001	OCO	626
3713.680	2.693	1.481-022	21111	11101	OCO	626
3713.719	2.693	5.632-022	21111	11101	OCO	626
3713.803	2.693	2.187-023	22211	12201	OCO	626
3714.781	2.692	1.685-018	10011	00001	OCO	626
3723.249	2.686	2.783-019	11111	01101	OCO	626
3723.310	2.686	1.135-019	12211	01101	OCO	626
3726.365	2.684	1.875-023	14411	04401	OCO	626
3726.610	2.683	3.683-021	12211	02201	OCO	626
3726.636	2.683	1.141-020	12211	02201	OCO	626
3727.377	2.683	4.643-022	13311	03301	OCO	626
3727.700	2.683	1.295-022	13311	03301	OCO	626
3740.620	2.673	1.580-023	001	000	HOH	181
3748.270	2.668	2.920-021	001	000	HOH	171
3755.920	2.662	7.890-018	001	000	HOH	161
3757.500	2.661	7.410-026	22203	01101	OCO	626
3799.484	2.632	2.768-025	30012	20003	OCO	626
3814.250	2.622	7.700-023	20011	10002	OCO	626
3831.980	2.610	9.151-026	30011	20002	OCO	626
3858.113	2.592	5.104-024	21111	11102	OCO	626
3889.545	2.571	1.199-025	22211	12202	OCO	626
3927.544	2.546	1.205-026	01121	10001	OCO	626
3980.601	2.512	7.440-026	01121	02201	OCO	626
3987.610	2.508	1.488-024	30002	00001	OCO	628
4005.940	2.496	8.184-025	00021	01101	OCO	626
4023.480	2.485	7.440-026	30002	00001	OCO	627
4030.318	2.481	3.720-026	0112	10002	OCO	626
4167.910	2.399	8.928-026	30001	00001	OCO	628

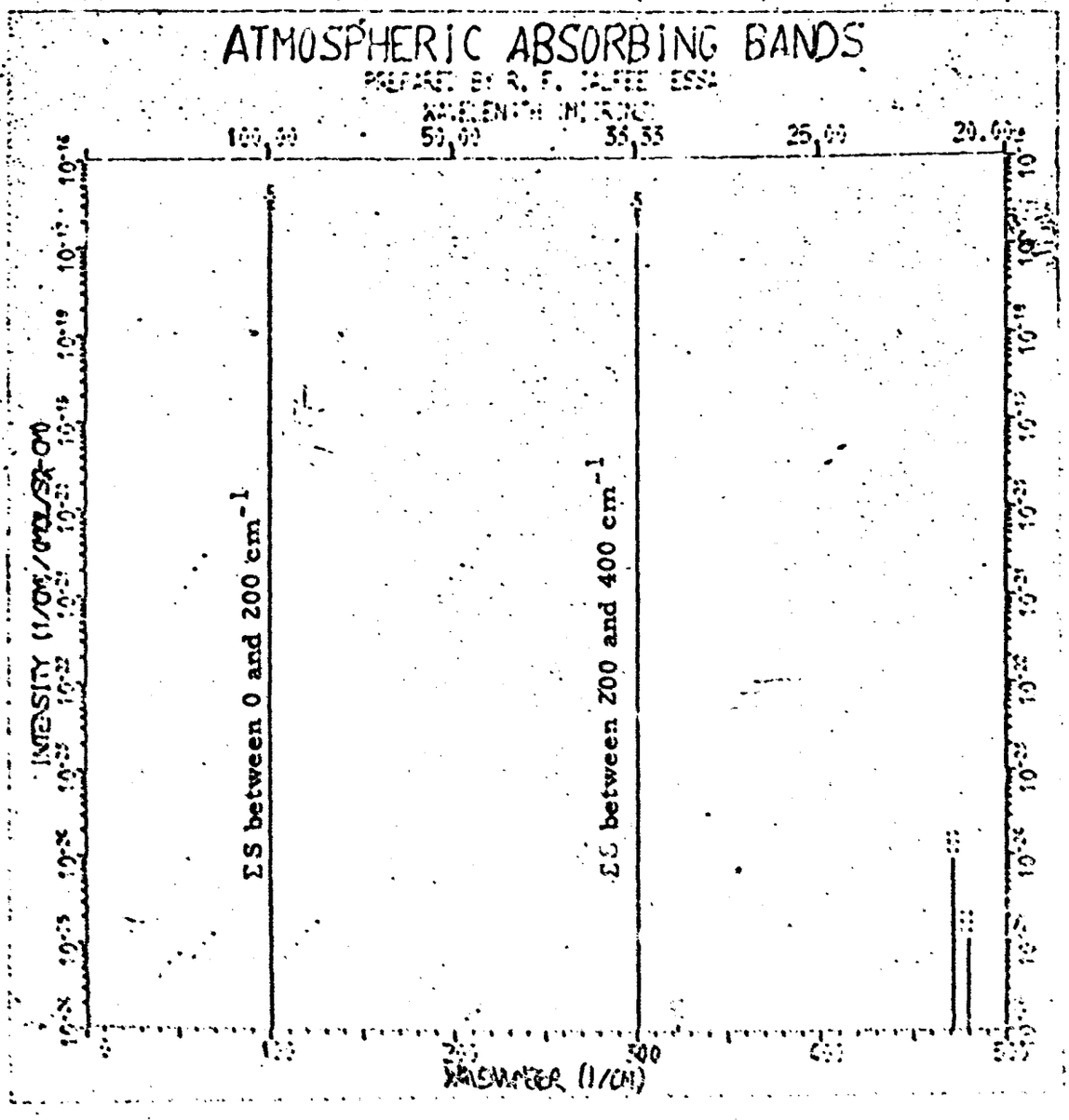
4340.000	2.304	6.966-020	2	0	CO	26
4416.150	2.264	3.720-026	31104	00001	OCO	626
4417.379	2.264	4.464-020	0002	0000	NNO	446
4485.600	2.229	1.562-026	01121	01101	OCO	638
4508.749	2.218	1.860-025	00021	00001	OCO	638
4524.880	2.210	1.711-026	00021	00001	OCO	637
4527.280	2.209	1.302-027	31103	00001	OCO	636
4529.870	2.208	2.232-026	40004	01101	OCO	626
4578.090	2.184	1.786-026	32203	01101	OCO	626
4591.118	2.178	2.046-025	31103	00001	OCO	626
4611.310	2.169	3.720-026	31114	11101	OCO	626
4614.779	2.167	1.042-024	01121	01101	OCO	628
4630.164	2.160	5.580-021	1201	0000	NNO	446
4630.370	2.160	9.672-026	01121	01101	OCO	627
4639.502	2.155	1.302-023	00021	00001	OCO	628
4655.205	2.148	1.265-024	00021	00001	OCO	627
4666.720	2.143	2.010-022	030	000	HOH	161
4673.680	2.140	1.488-025	22213	02201	OCO	636
4683.120	2.135	1.860-027	31102	00001	OCO	636
4685.780	2.134	1.860-025	30014	10002	OCO	636
4687.796	2.133	5.208-025	30014	10001	OCO	626
4692.180	2.131	2.604-025	20013	00001	OCO	638
4708.520	2.124	5.952-024	21113	01101	OCO	636
4718.350	2.119	4.464-026	20013	00001	OCO	637
4721.920	2.118	4.836-026	20013	00001	OCO	828
4730.828	2.114	1.860-020	2001	0000	NNO	446
4733.500	2.113	6.696-025	23313	03301	OCO	626
4743.700	2.108	3.348-024	21113	01101	OCO	628
4748.058	2.106	2.678-023	20013	00001	OCO	636
4753.450	2.104	2.976-025	31102	00001	OCO	626
4755.705	2.103	3.571-024	31114	11102	OCO	626
4768.541	2.097	2.604-023	22213	02201	OCO	626
4784.675	2.090	1.488-025	20023	00011	OCO	626
4786.688	2.089	1.190-024	31113	11101	OCO	626
4790.571	2.087	1.562-023	30014	10002	OCO	626
4791.260	2.087	4.687-023	20013	00001	OCO	628
4807.692	2.080	1.339-021	21113	01101	OCO	626
4814.570	2.077	1.339-024	20012	00001	OCO	638
4821.500	2.074	7.440-024	20013	00001	OCO	627
4839.737	2.066	1.376-023	30013	10001	OCO	626
4853.620	2.060	9.072-021	20013	00001	OCO	626
4871.460	2.053	4.762-023	21112	01101	OCO	636
4887.390	2.046	2.976-022	20012	00001	OCO	636
4896.185	2.042	8.928-024	21112	01101	OCO	628
4904.850	2.039	1.116-022	20012	00001	OCO	628
4925.010	2.030	4.464-025	20011	00001	OCO	638
4928.910	2.029	1.488-024	21112	01101	OCO	627
4931.083	2.028	9.672-024	31113	11102	OCO	626
4939.350	2.025	2.306-023	20012	00001	OCO	627
4942.512	2.023	1.414-022	30013	10002	OCO	626
4946.807	2.022	5.952-024	31112	11101	OCO	626
4953.363	2.019	1.042-022	22212	02201	OCO	626
4959.667	2.016	8.370-023	30012	10001	OCO	626
4965.381	2.014	5.312-021	21112	01101	OCO	626

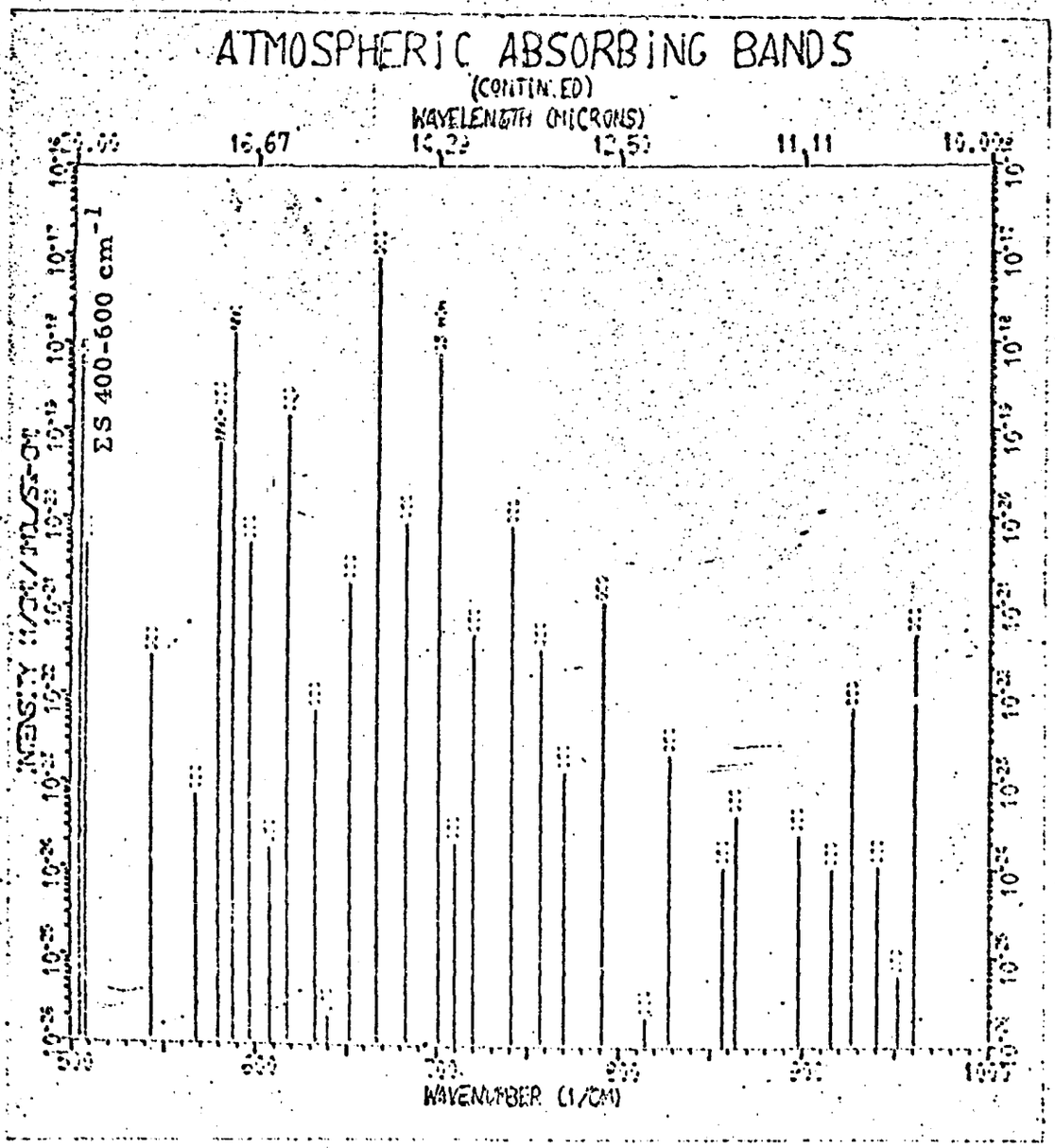
4977.830	2.009	3.497-020	20012	00001	OCO	626
4991.350	2.003	2.120-022	20011	00001	OCO	636
5013.785	1.995	3.422-023	21111	01101	OCO	636
5028.780	1.989	2.976-025	22211	02201	OCO	636
5042.570	1.983	2.269-023	20011	00001	OCO	628
5062.442	1.975	2.381-023	30012	10002	OCO	626
5064.680	1.974	2.604-024	21111	01101	OCO	628
5068.910	1.973	6.324-024	20011	00001	OCO	627
5099.660	1.961	1.123-020	20011	00001	OCO	626
5114.894	1.955	3.088-023	30011	10001	OCO	626
5123.200	1.952	2.128-021	21111	01101	OCO	626
5139.401	1.946	4.092-023	22211	02201	OCO	626
5168.600	1.935	3.720-025	01121	00001	OCO	636
5217.669	1.917	2.344-024	30011	10002	OCO	626
5234.950	1.910	1.830-020	110	000	HOH	161
5247.830	1.906	1.012-024	10022	01101	OCO	626
5276.770	1.895	1.800-018	012	010	HOH	161
5277.070	1.895	1.488-025	01121	00001	OCO	628
5291.160	1.890	5.506-024	02221	01101	OCO	626
5294.970	1.889	2.678-026	01121	00001	OCO	627
5310.510	1.883	1.810-021	011	000	HOH	181
5315.730	1.881	3.980-023	01121	00001	OCO	626
5320.860	1.879	3.360-022	011	000	HOH	171
5331.210	1.876	9.060-019	011	000	HOH	161
5349.360	1.869	5.059-025	10021	01101	OCO	626
5584.391	1.791	7.068-025	00031	10001	OCO	626
5670.080	1.764	5.952-026	01131	11102	OCO	626
5687.166	1.758	7.514-025	00031	10002	OCO	626
5809.460	1.721	3.720-027	10021	00001	OCO	638
5813.020	1.720	2.976-026	11122	01101	OCO	628
5858.022	1.707	3.720-025	10022	00001	OCO	628
5885.336	1.699	2.976-026	10022	00001	OCO	627
5904.470	1.694	3.720-026	31114	01101	OCO	636
933.990	1.685	2.976-026	31114	01101	OCO	628
5951.600	1.680	1.786-025	30014	00001	OCO	636
5955.840	1.679	2.976-026	11124	01101	OCO	628
5959.954	1.678	3.348-025	10021	00001	OCO	628
5972.520	1.674	2.530-025	32214	02201	OCO	626
5987.020	1.670	1.488-026	10021	00001	OCO	627
5993.581	1.668	3.571-025	30014	00001	OCO	628
5998.569	1.667	3.348-025	40015	10002	OCO	626
6000.520	1.667	1.674-028	41103	00001	OCO	626
6020.795	1.661	9.300-024	31114	01101	OCO	626
6026.630	1.659	1.488-026	30013	00001	OCO	638
6033.478	1.657	4.092-026	30014	00001	OCO	627
6072.343	1.647	1.042-025	40014	10001	OCO	626
6075.983	1.646	4.538-023	30014	00001	OCO	626
6088.210	1.643	2.381-025	31113	01101	OCO	636
6100.300	1.639	2.083-025	31113	01101	OCO	628
6119.618	1.634	2.902-024	30013	00001	OCO	636
6127.782	1.632	2.381-024	30013	00001	OCO	628
6141.300	1.628	1.860-026	30012	00001	OCO	638
6149.760	1.626	1.786-025	41114	11102	OCO	626
6170.090	1.621	1.265-024	32213	02201	OCO	626

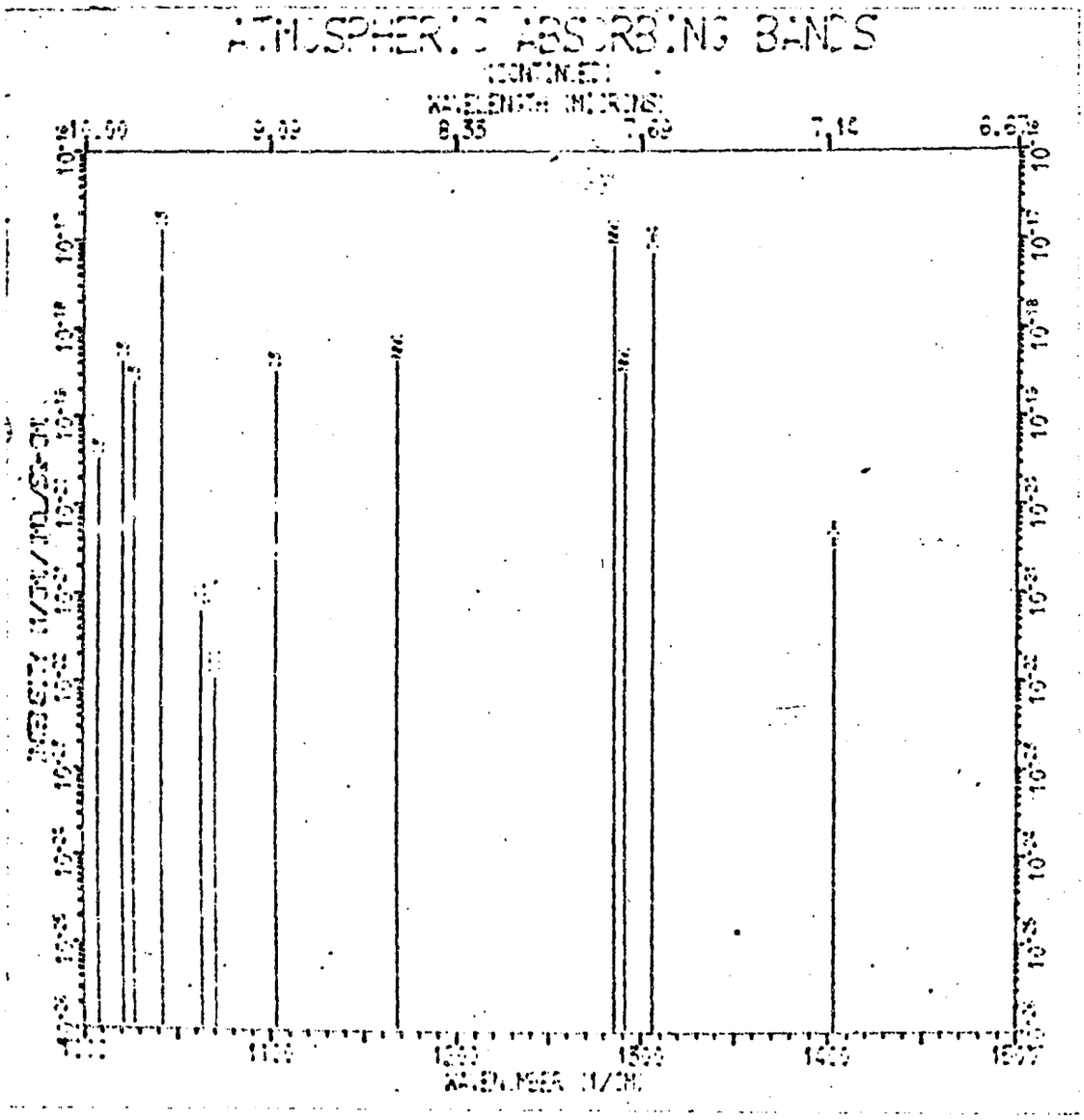
6175.118	1.619	2.269-024	40014	10002	OCO	626
6175.950	1.619	3.199-025	30013	00001	OCO	627
6196.174	1.614	5.357-023	31113	01101	OCO	626
6205.503	1.611	1.265-024	40013	10001	OCO	626
6227.924	1.606	4.271-022	30013	00001	OCO	626
6241.964	1.602	4.613-024	30012	00001	OCO	636
6243.570	1.602	4.092-025	31112	01101	OCO	636
6254.592	1.599	1.414-024	30012	00001	OCO	628
6265.170	1.596	1.190-025	31112	01101	OCO	628
6298.110	1.588	2.753-025	30012	00001	OCO	627
6308.278	1.585	2.455-024	40013	10002	OCO	626
6318.170	1.583	1.786-025	41113	11102	OCO	626
6346.265	1.576	1.190-024	40012	10001	OCO	626
6347.854	1.575	4.271-022	30012	00001	OCO	626
6356.293	1.573	6.547-023	31112	01101	OCO	626
6359.287	1.573	1.116-024	32212	02201	OCO	626
6360.000	1.572	2.824-022	3	0	CO	26
6363.616	1.571	1.265-024	30011	00001	OCO	636
6374.497	1.569	3.348-026	11122	00001	OCO	636
6397.545	1.563	1.190-025	31111	01101	OCO	636
6429.172	1.555	1.116-025	30011	00001	OCO	628
6449.040	1.551	2.232-026	40012	10002	OCO	626
6463.480	1.547	2.083-026	30011	00001	OCO	627
6466.440	1.546	1.042-025	20023	01101	OCO	626
6498.670	1.539	1.190-025	12222	01101	OCO	626
6503.081	1.538	4.985-023	30011	00001	OCO	626
6532.653	1.531	1.302-025	40011	10001	OCO	626
6536.445	1.530	9.523-024	31111	01101	OCO	626
6537.958	1.530	2.232-024	11122	00001	OCO	626
6562.444	1.524	2.232-025	32211	02201	OCO	626
6616.064	1.511	8.556-027	21122	10002	OCO	626
6635.428	1.507	2.232-026	40011	10002	OCO	626
6670.770	1.499	1.786-025	12221	01101	OCO	626
6679.709	1.497	2.827-024	11121	00001	OCO	626
6710.320	1.490	7.440-026	20021	01101	OCO	626
6715.360	1.489	3.348-026	10032	10002	OCO	636
6728.360	1.486	5.952-026	00031	00001	OCO	638
6745.115	1.483	2.678-024	01131	01101	OCO	636
6752.460	1.481	1.116-026	00031	00001	OCO	637
6755.100	1.480	3.530-021	120	000	HOH	161
6780.215	1.475	1.637-023	00031	00001	OCO	636
6804.369	1.470	5.580-026	10032	10001	OCO	626
6860.410	1.458	2.009-025	03331	03301	OCO	626
6867.280	1.456	1.116-025	11131	11101	OCO	626
6870.670	1.455	5.208-027	00031	00001	OCO	828
6870.796	1.455	2.411-025	11132	11102	OCO	626
6871.520	1.455	5.640-020	021	000	HOH	161
6885.150	1.452	4.018-025	01131	01101	OCO	628
6897.751	1.450	4.241-024	02231	02201	OCO	626
6897.800	1.450	5.952-026	00041	00011	OCO	626
6905.770	1.448	1.711-024	10031	10001	OCO	62
6907.144	1.448	2.902-024	10032	10002	OCO	626
6922.210	1.445	5.208-024	00031	00001	OCO	628
6935.150	1.442	2.262-022	01131	01101	OCO	626

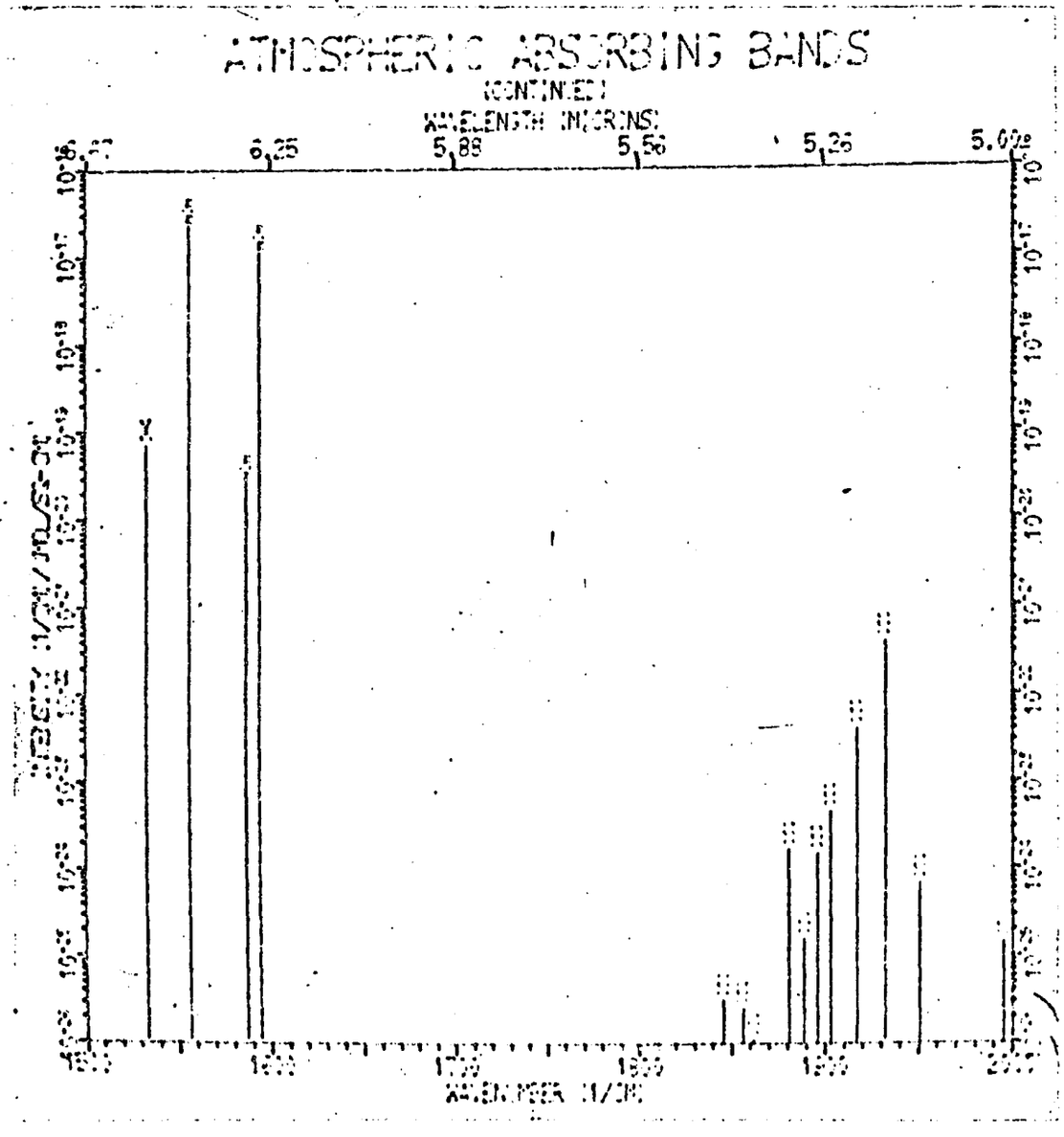
6945.610	1.440	1.116-024	00031	00001	OCO	627
6972.578	1.434	1.495-021	00031	00001	OCO	626
7008.545	1.427	4.464-026	10031	10002	OCO	626
7201.480	1.389	5.290-020	200	000	HOH	161
7249.930	1.379	7.470-019	101	000	HOH	161
7283.981	1.373	1.860-025	40015	00001	OCO	626
7332.600	1.364	1.860-026	40014	00001	OCO	636
7339.300	1.363	2.976-026	40014	00001	OCO	628
7414.800	1.349	4.464-026	41114	01101	OCO	626
7445.040	1.343	5.290-021	002	000	HOH	161
7460.530	1.340	4.278-024	40014	00001	OCO	626
7466.400	1.339	2.232-026	40013	00001	OCO	628
7481.510	1.337	1.116-025	40013	00001	OCO	636
7583.265	1.319	8.333-025	41113	01101	OCO	626
7593.690	1.317	1.064-023	40013	00001	OCO	626
7600.130	1.316	7.440-026	40012	00001	OCO	636
7616.620	1.313	1.116-028	51102	00001	OCO	626
7734.452	1.293	2.790-024	40012	00001	OCO	626
7743.700	1.291	4.464-026	21123	00001	OCO	626
7749.100	1.290	1.116-026	40011	00001	OCO	636
7757.621	1.289	2.976-025	41112	01101	OCO	626
7901.479	1.266	1.488-025	21122	00001	OCO	626
7920.840	1.262	1.860-025	40011	00001	OCO	626
7929.920	1.261	1.934-026	11132	01101	OCO	636
7961.290	1.256	2.381-026	41111	01101	OCO	626
7981.180	1.253	2.232-025	10032	00001	OCO	636
8000.803	1.250	4.092-027	20033	10001	OCO	626
8056.024	1.241	4.464-026	21121	00001	OCO	626
8070.910	1.239	5.952-026	11131	01101	OCO	636
8084.060	1.237	1.934-025	12232	02201	OCO	626
8089.040	1.236	7.068-025	10031	00001	OCO	636
8103.578	1.234	2.046-025	20033	10002	OCO	626
8120.104	1.232	2.009-025	10032	00001	OCO	628
8128.783	1.230	7.068-026	20032	10001	OCO	626
8135.886	1.229	8.035-024	11132	01101	OCO	626
8154.470	1.226	3.720-026	10032	00001	OCO	627
8192.556	1.221	4.241-023	10032	00001	OCO	626
8220.363	1.216	2.009-025	10031	00001	OCO	628
8231.558	1.215	1.228-025	20032	10002	OCO	626
8243.163	1.213	1.079-025	20031	10001	OCO	626
8254.800	1.211	1.637-025	12231	02201	OCO	626
8255.390	1.211	4.464-026	10031	00001	OCO	627
8273.950	1.209	2.400-022	130	000	HOH	161
8276.767	1.208	9.226-024	11131	01101	OCO	626
8293.957	1.206	6.138-023	10031	00001	OCO	626
8373.820	1.194	3.600-021	031	000	HOH	161
8761.570	1.141	3.600-022	210	000	HOH	161
8807.000	1.135	4.980-020	111	000	HOH	161
9000.130	1.111	1.500-021	012	000	HOH	161
9833.580	1.017	4.800-023	041	000	HOH	161
10284.000	0.972	1.500-023	220	000	HOH	161
10328.710	0.968	2.100-021	121	000	HOH	161
10524.300	0.950	6.000-024	022	000	HOH	161
10599.660	0.943	2.700-022	300	000	HOH	161

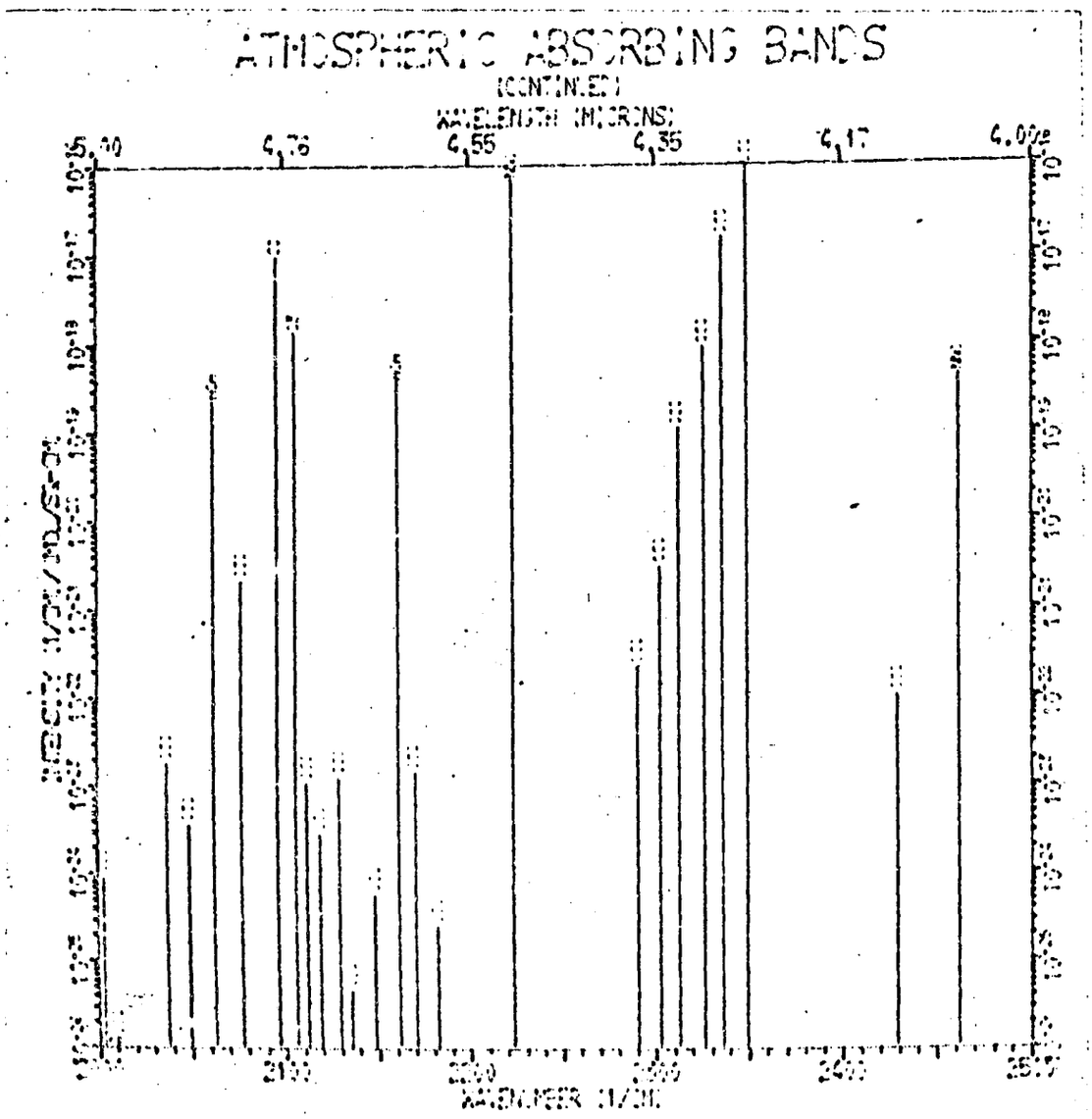
10613.410	0.942	2.130-020	201	000	HOH	161
10868.860	0.920	5.700-022	102	000	HOH	161
11032.400	0.906	2.400-021	003	000	HOH	161
11813.190	0.847	6.260-023	131	000	HOH	161
12139.200	0.824	1.960-023	310	000	HOH	161
12151.260	0.823	1.010-021	211	000	HOH	161

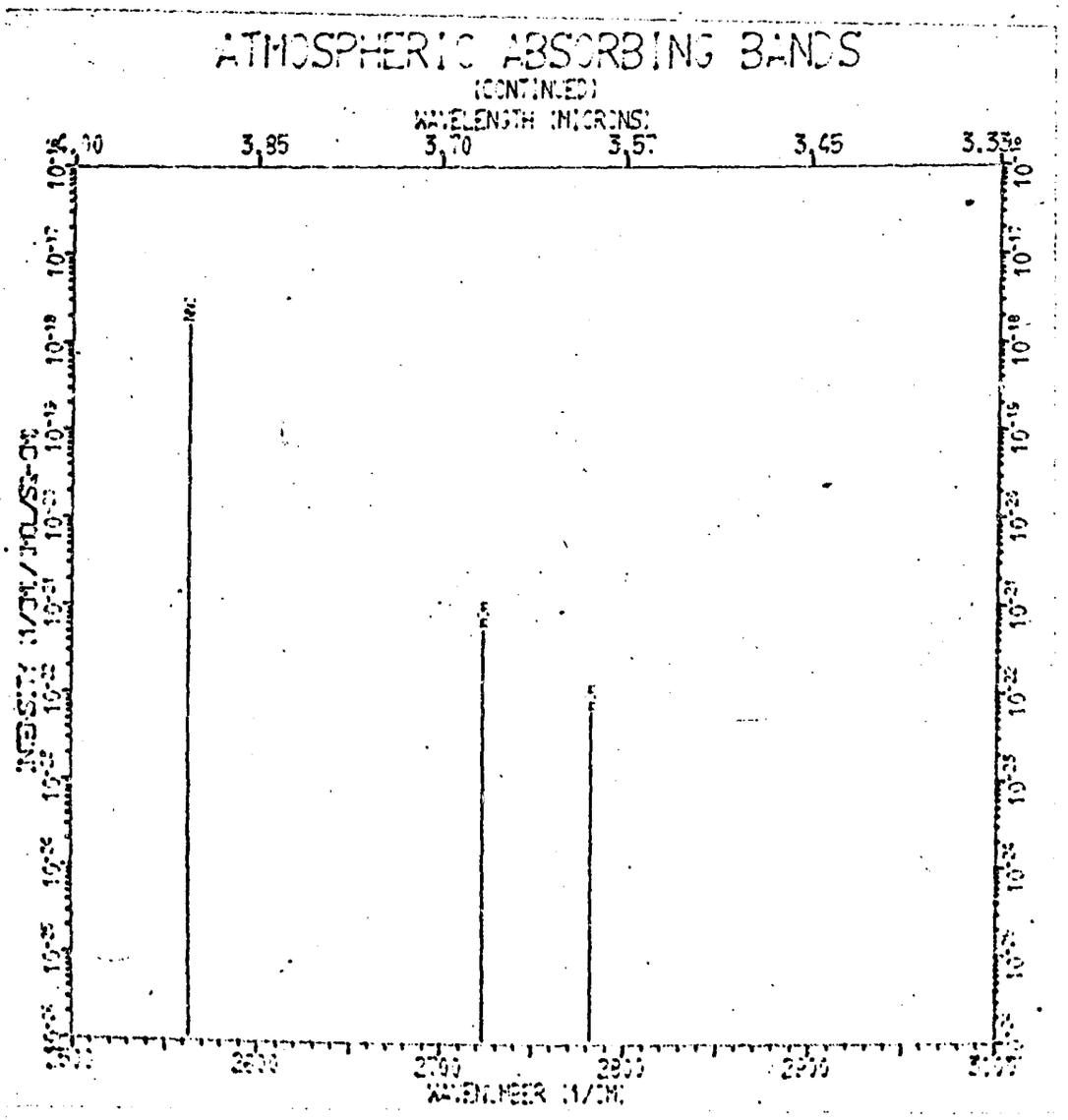

ATMOSPHERIC ABSORBING BANDS
PREPARED BY R. F. CALFEE ESSA
WAVELENGTH IN MICRONS
100.00
50.00
35.33
25.00
20.00
INTENSITY (1/CM/MOLECULE-CM)
ΣS between 0 and 200 cm⁻¹
ΣS between 200 and 400 cm⁻¹
WAVENUMBER (1/CM)
100
200
300
400

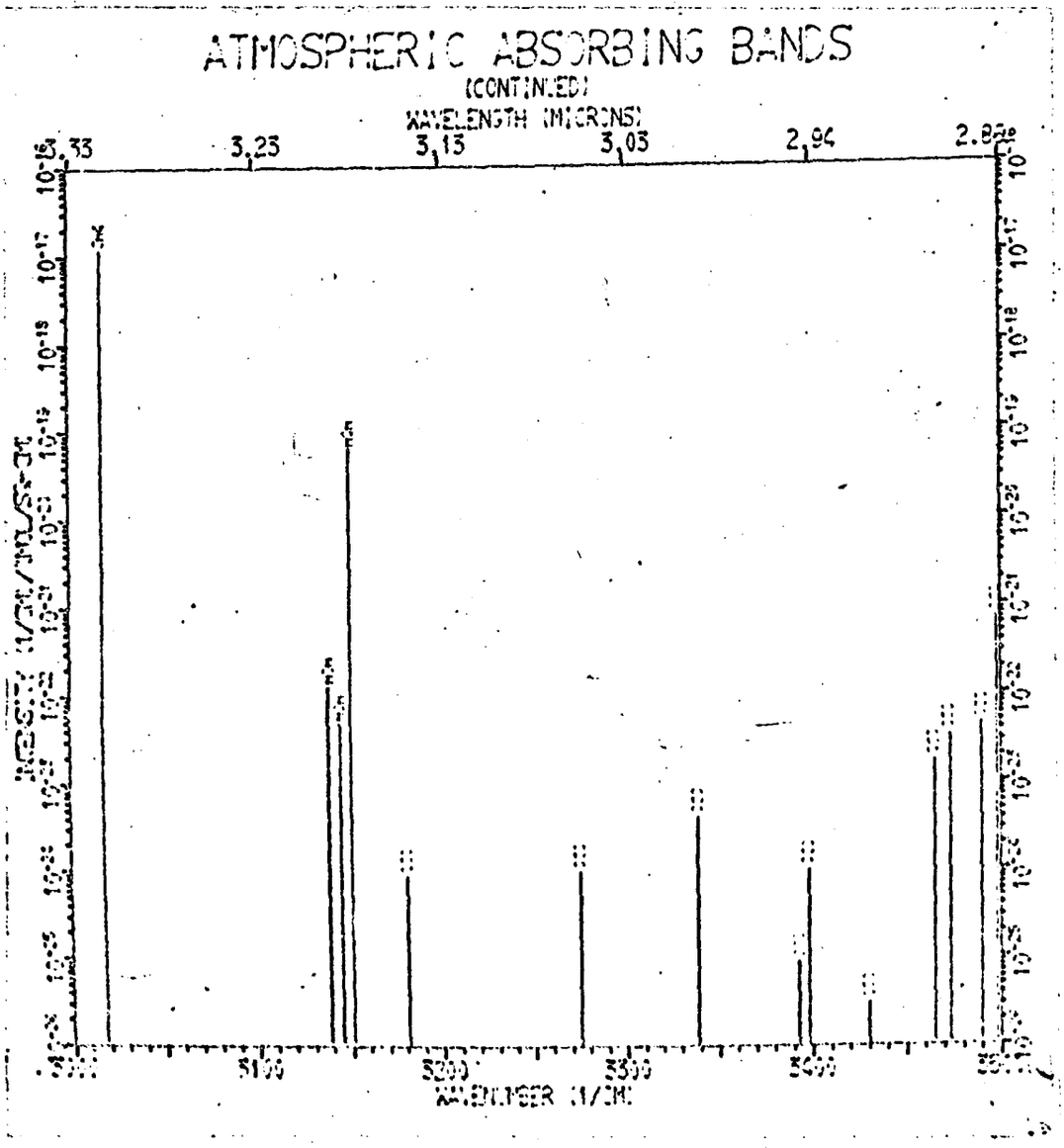

ATMOSPHERIC ABSORBING BANDS
(CONTINUED)
WAVELENGTH (MICRONS)
16.67
11.11
ΣS 400-600 cm⁻¹
WAVENUMBER (1/CM)

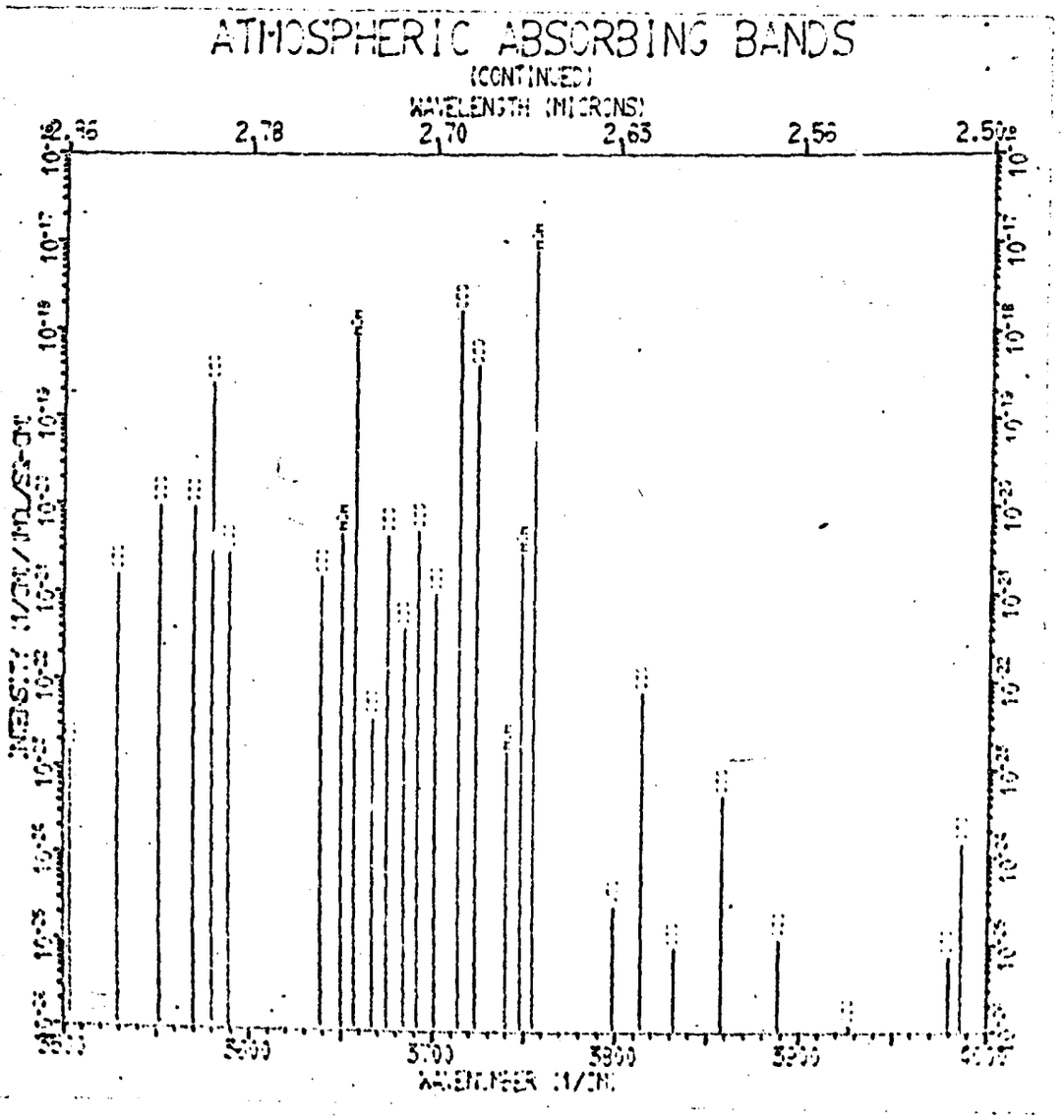

ATMOSPHERIC ABSORBING BANDS
(CONTINUED)
WAVELENGTH (MICRONS)
8.35
7.14

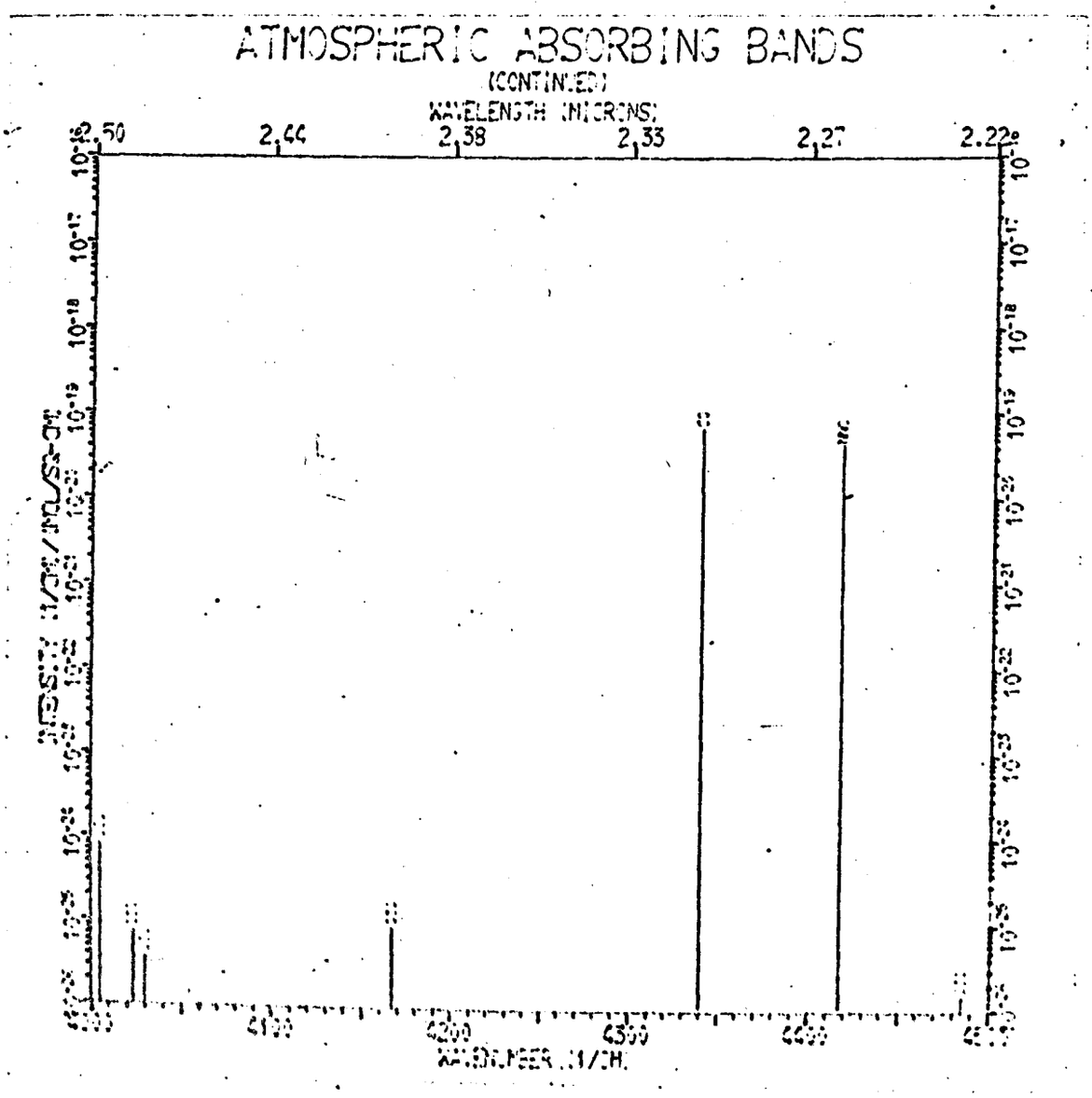

ATMOSPHERIC ABSORBING BANDS
(CONTINUED)
WAVELENGTH (MICRONS)
6.25
5.88
5.56
5.26
5.00
WAVENUMBER (1/CM)

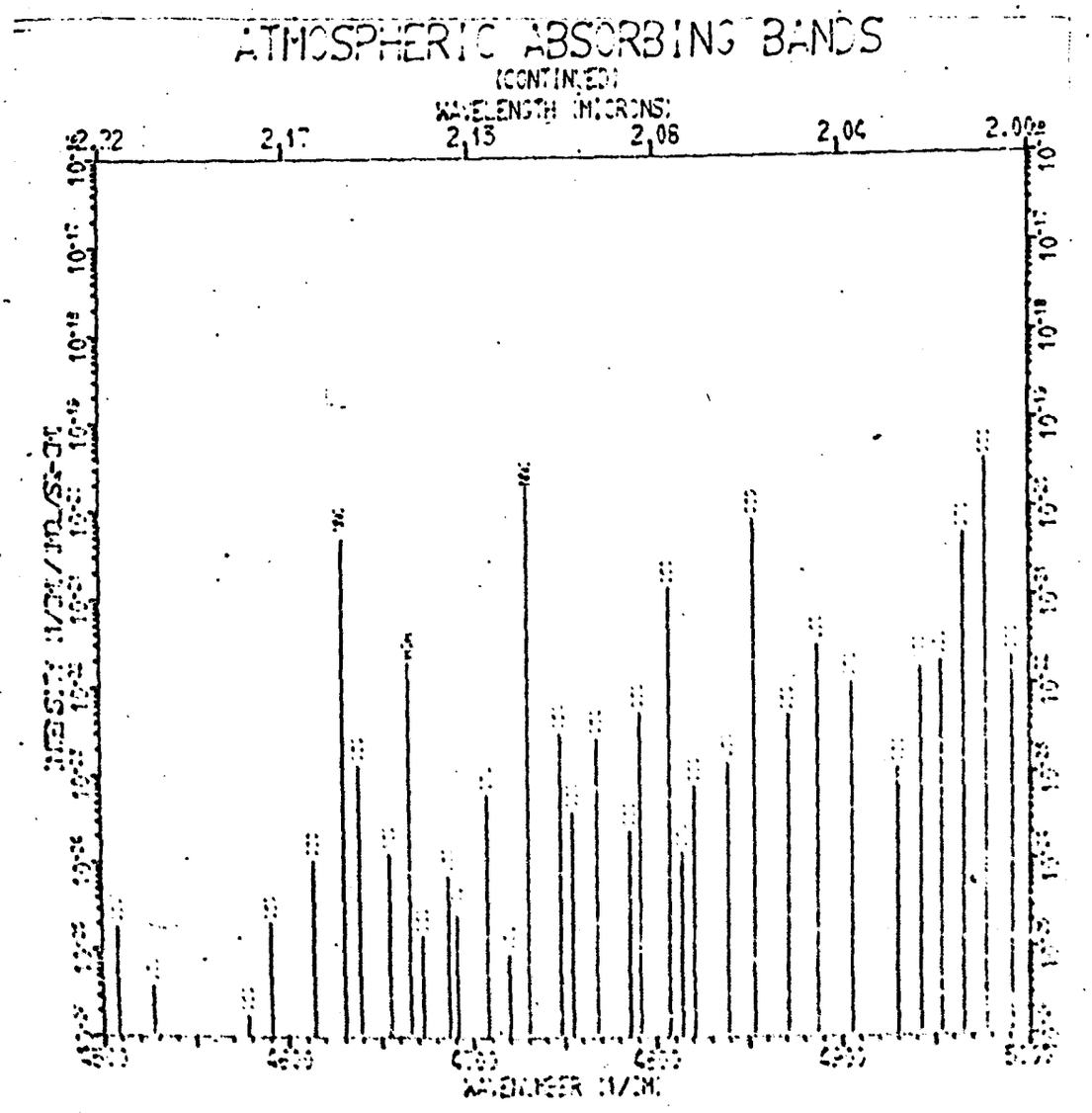

ATMOSPHERIC ABSORBING BANDS
(CONTINUED)
WAVELENGTH (MICRONS)
4.76
4.55
4.35
4.17
4.00
WAVENUMBER (1/CM)

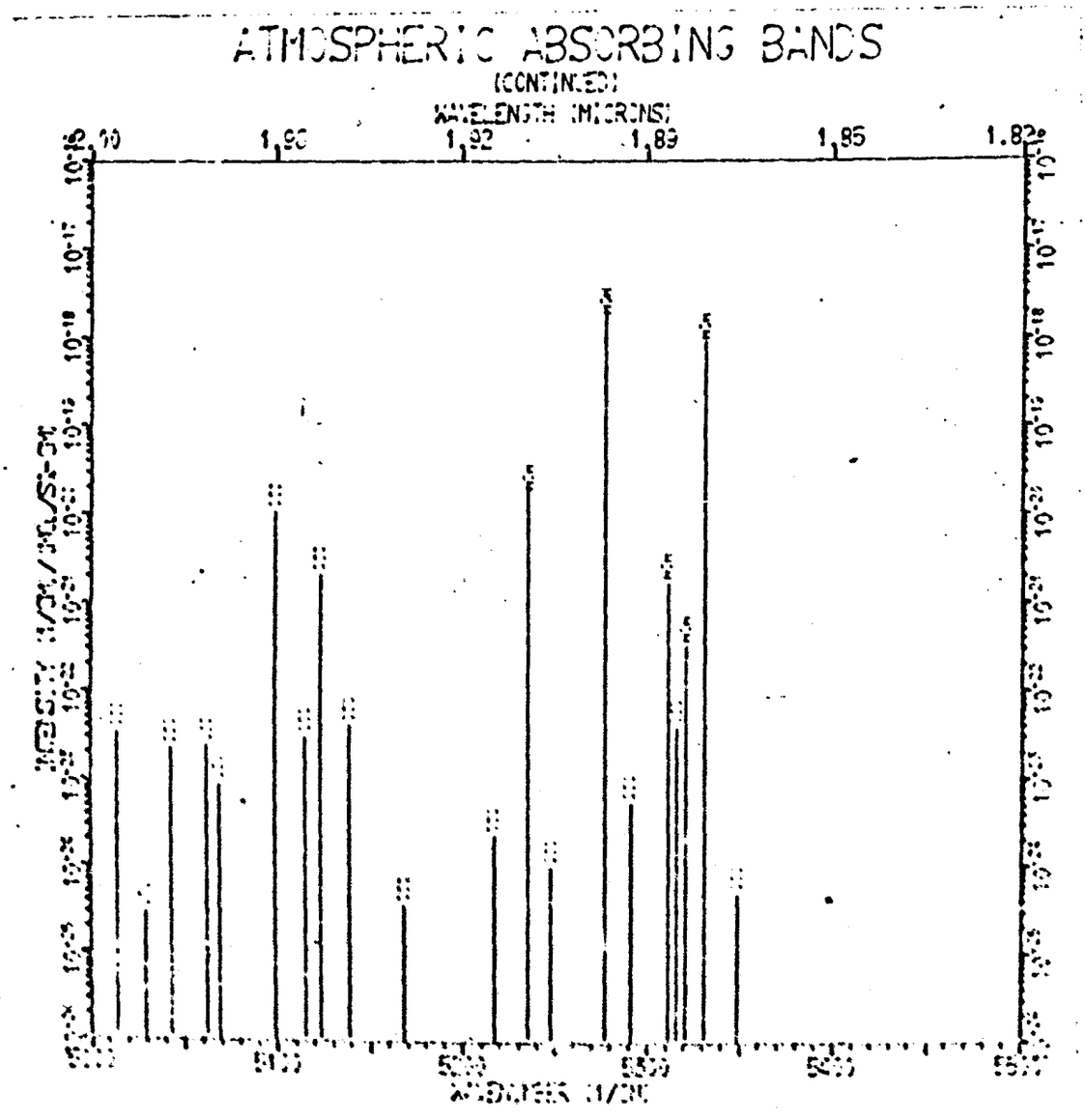












ATMOSPHERIC ABSORBING BANDS

(CONTINUED)